# W width & W/Z cross sections at the Tevatron

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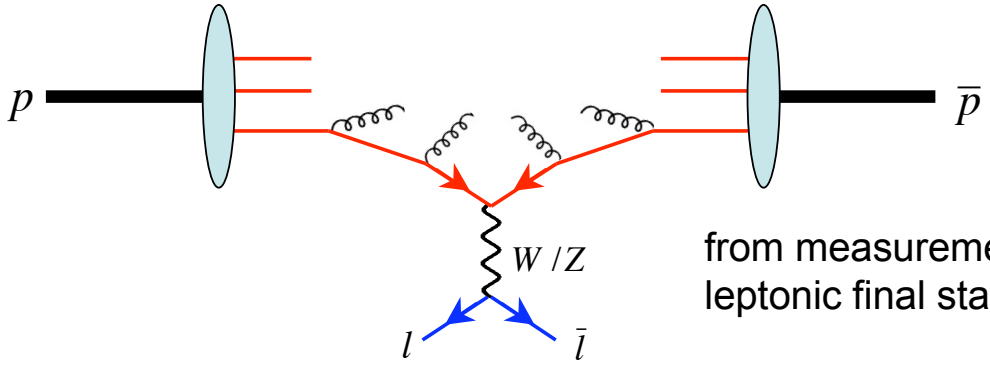
on behalf of the CDF & DØ Collaborations

# Motivation for Measurements

1. **QCD:**
   - NNLO calculation of $\sigma_z / \sigma_w$
   - PDF measurements from Z rapidity and FB lepton asymmetry (W)
   - QCD radiation from $p_T(Z)$ at low $p_T$ (non-perturb) and high $p_T$ (NLO)

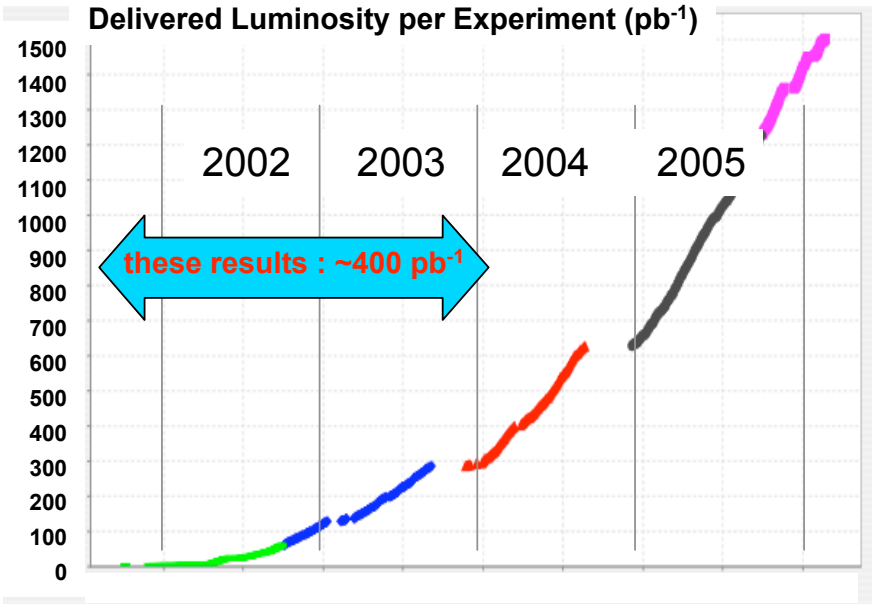


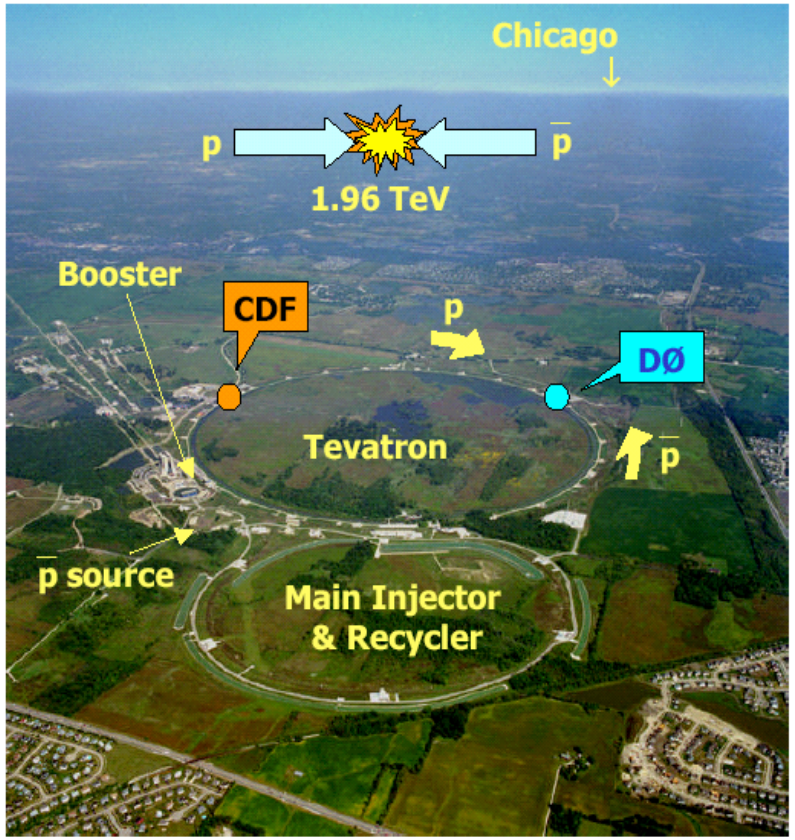

from measurement of leptonic final states

2. **SM Parameters:** CKM ($V_{CS}$), $\Gamma_W$, quark couplings

3. **Optimising detector understanding for new physics searches**

# Data Samples



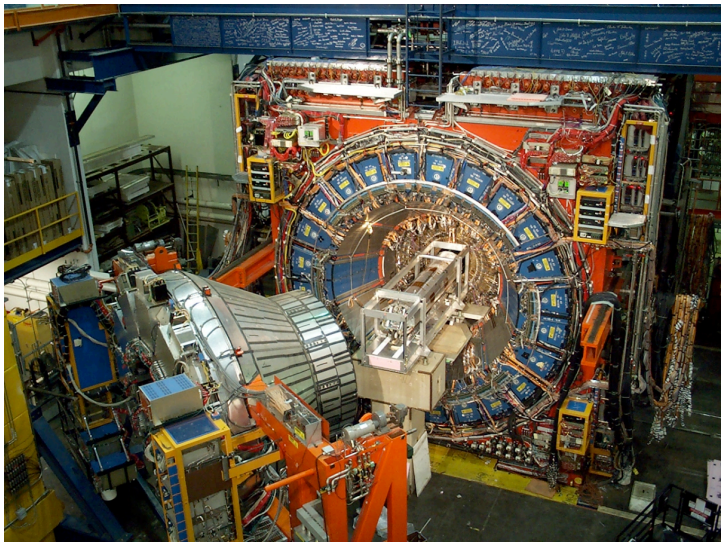

W Factory

| Mode | Events/Week/Exp. (after trigger & cuts) |
|---|---|
| $W \rightarrow e\nu$ | ~ 15,000 |
| $Z \rightarrow ee$ | ~ 1,500 |

Now operating in precision regime:

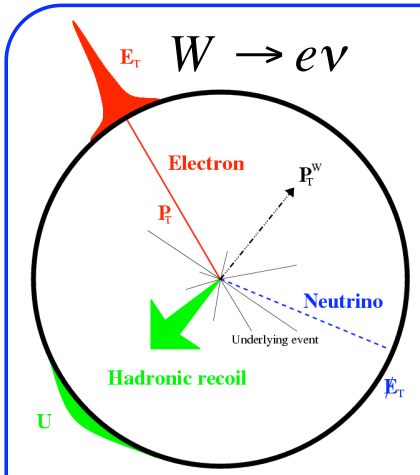
$$N(Z \rightarrow ee)_{\text{Tevatron}} > N(W)_{\text{LEP}}$$

# Detectors

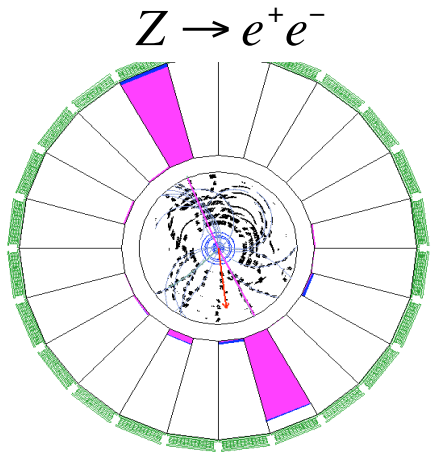


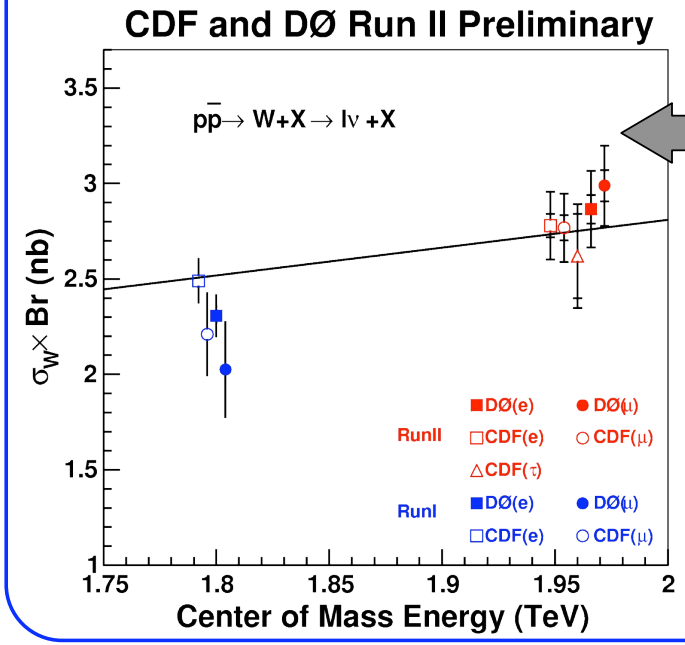
| | CDF | DØ |
|---|---|---|
| Tracking to $\|\eta\| < 3$ | Drift Chamber + Si | Fiber + Si |
| Calorimetry $\|\eta\| < 4$ | Pb/Steel + Scintillator | Ur + Liquid Ar |
| Muons | $\|\eta\| < 1$ | $\|\eta\| < 2$ |

# Inclusive Cross Sections



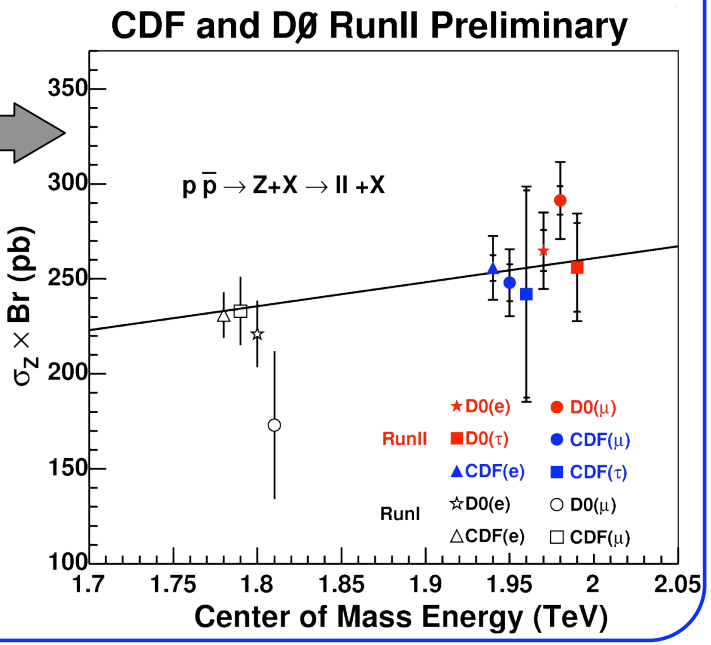

- Standard boson selections ( $l+\not{E}_T$ ; $l^+l^-$ )
- Mostly employ central lepton triggers.
- 1-2% systematic uncertainties (w/o luminosity):
  - PDF's
  - lepton & trigger efficiencies
  - backgrounds
- Results are in good agreement with NNLO QCD predictions.




- ~70-350 $pb^{-1}$ results.
- NNLO predictions **(Hamberg, van Neerven & Matsuura 1991; Anastasiou et al. 2004)**

**CDF : PRL 94, 091803 (2005)**



# Luminosity from W/Z Production

- Present experimental Systematic is **2%** (excluding luminosity) & NNLO theory uncertainty is 2-3 %

- Current lumi determination uses forward Cherenkov detector : **uncertainty= 6%**

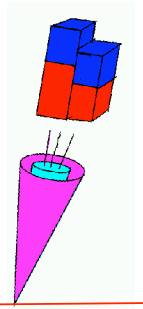
$$\frac{\sigma(L)}{L} = 4.0\% \oplus 4.4\%$$

$\sigma_{\mathrm{TOT}}(p\bar{p})$ $\sigma_{\mathrm{EXP}}$ (lumi detector acceptance)

- Already a viable (integrated) luminosity method.
- Work ongoing to identify optimal observables etc.
- Another possibility is to explicitly measure ratios : $\sigma_X / \sigma_W$

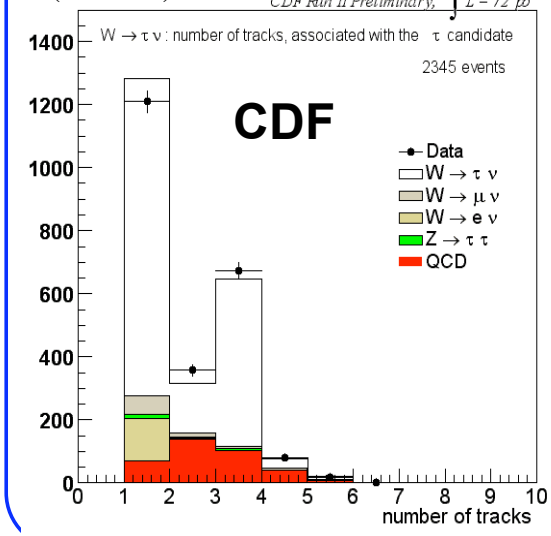
# Tau Channel

- Interesting channel :
  - to test 3rd generation lepton universality,
  - as a benchmark for searches (especially MSSM Higgs).
- Experimentally challenging.



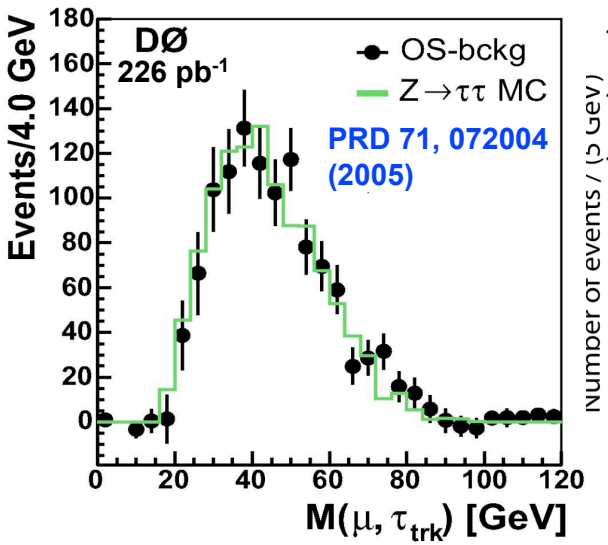
$$\sigma_W \cdot BR(W \to \tau\nu) = 2.62 \pm 0.07\ (\text{stat}) \pm 0.21\ (\text{sys}) \pm 0.16\ (\text{lum})\ \text{nb}$$

$$\frac{BR(W \to \tau\nu)}{BR(W \to e\nu)} = 0.99 \pm 0.04\ (\text{stat}) \pm 0.07\ (\text{sys})$$



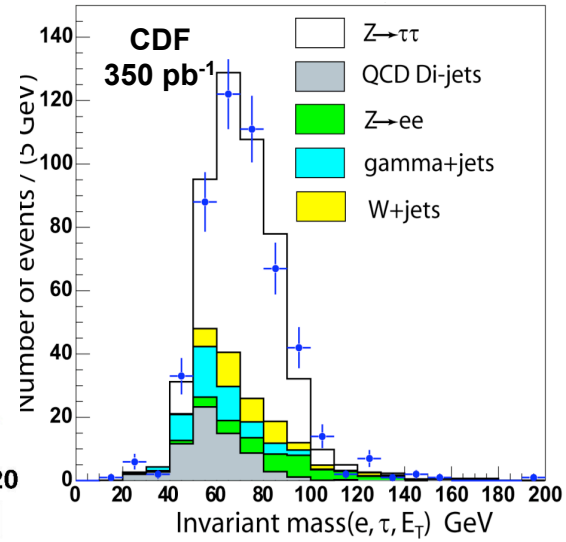

$$Z \to \tau(\mu)\tau(h/e)$$

$$\sigma_Z \cdot BR(Z \to \tau\tau) = 237 \pm 15\ (\text{stat}) \pm 18\ (\text{sys}) \pm 15\ (\text{lum})\ \text{pb}$$




$$Z \to \tau(e)\tau(h)$$

$$\sigma_Z \cdot BR(Z \to \tau\tau) = 265 \pm 20\ (\text{stat}) \pm 21\ (\text{sys}) \pm 15\ (\text{lum})\ \text{pb}$$



# Indirect W Width

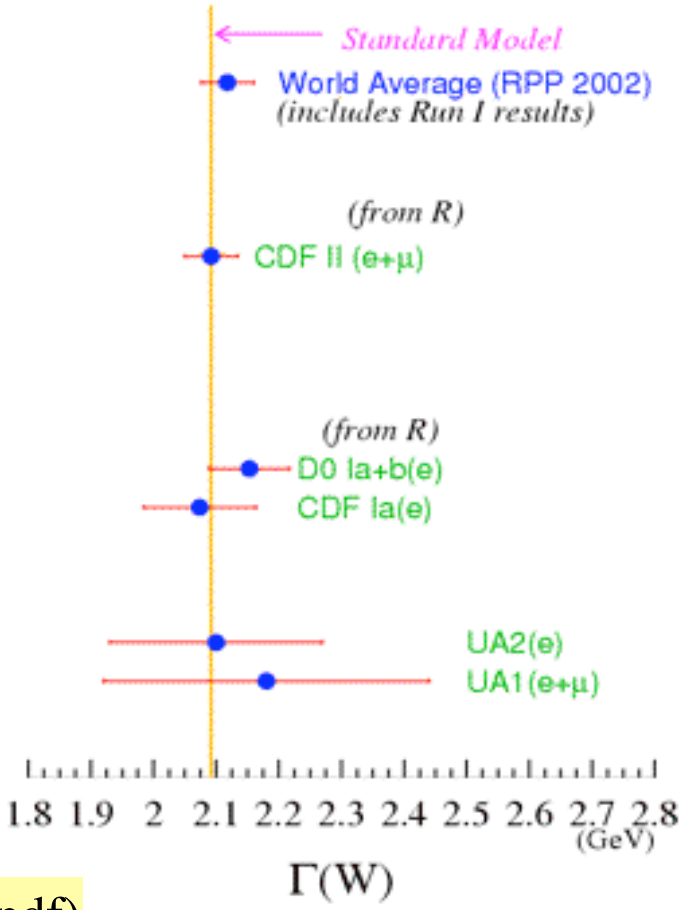
$$R = \frac{\sigma_W \cdot BR(W \to l\nu)}{\sigma_Z \cdot BR(Z \to l^+l^-)}$$

$$= \frac{\sigma_W}{\sigma_Z} \cdot \frac{\Gamma_Z}{\Gamma_{Z\to l^+l^-}} \cdot \frac{\Gamma_{W\to l\nu}}{\Gamma_W}$$

**SM :** $3.370 \pm 0.024$

**SM :** $226.4 \pm 0.3$ MeV

**LEP :** $BR(Z \to l^+l^-) = 0.033658 \pm 0.000023$




- Careful propagation of correlated systematics:

$$R = 10.84 \pm 0.15\ (\text{stat}) \pm 0.14\ (\text{syst})$$

$$\Gamma_W = 2.092 \pm 0.042\ \text{GeV}$$

CDF e+μ, 72 pb$^{-1}$
PRL 94, 091803 (2005)

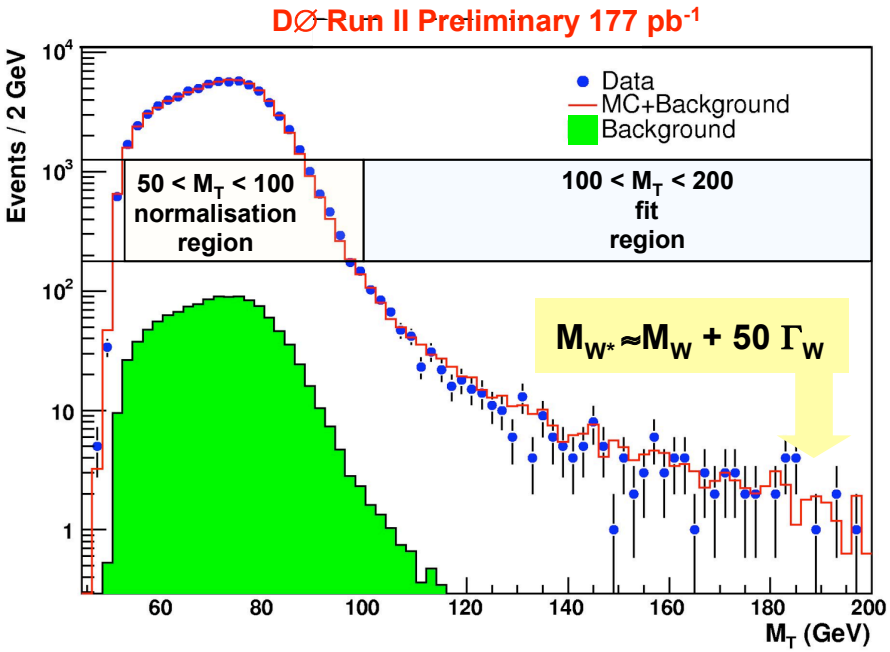
$$R = 10.82 \pm 0.16\ (\text{stat}) \pm 0.25\ (\text{syst}) \pm 0.13\ (\text{pdf})$$

DØ e, 177 pb$^{-1}$

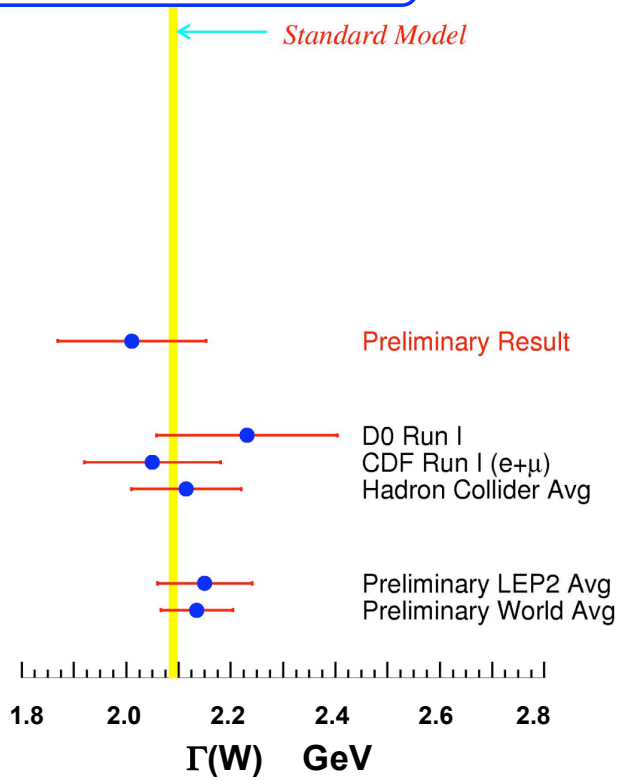
# Direct W Width

- Measure the tail of high mass Ws.

**Lineshape ≈ Breit-Wigner ($M_W$,$\Gamma_W$) ⊗ PDF's ⊗ Resolution**




$$\Gamma_W = 2.011 \pm 0.093\ (\text{stat}) \pm 0.107\ (\text{syst})\ \text{GeV}$$



# Vcs & Lepton Universality

**Indirect Determination**

$$\Gamma_W = 3\Gamma_W^0\left(1 + K_{QCD}\ (\alpha_S^3) \sum_{|\text{no top}|} |V_{qq'}|^2\right)$$

$$|V_{cs}|_{CDF} = 0.976 \pm 0.030$$

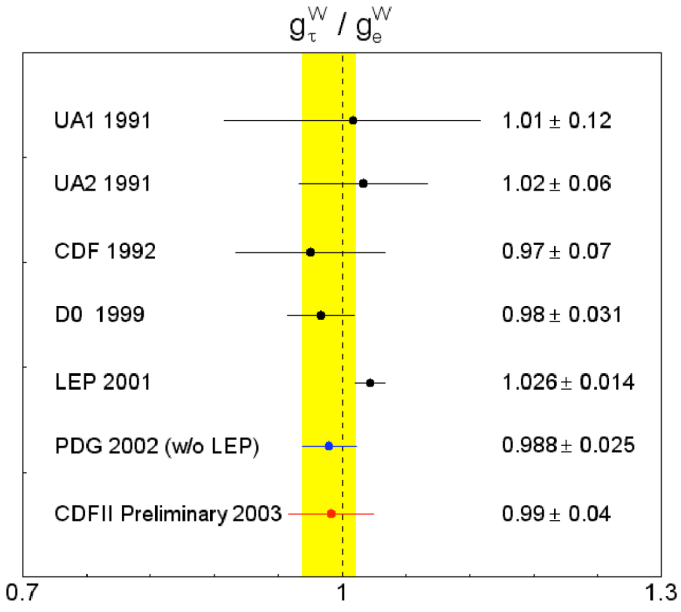
Comparable to LEP2 precision

$$\frac{g_\mu^W}{g_e^W}(CDF) = 0.991 \pm 0.012$$

$$\frac{g_\tau^W}{g_e^W}(CDF) = 0.99 \pm 0.04$$

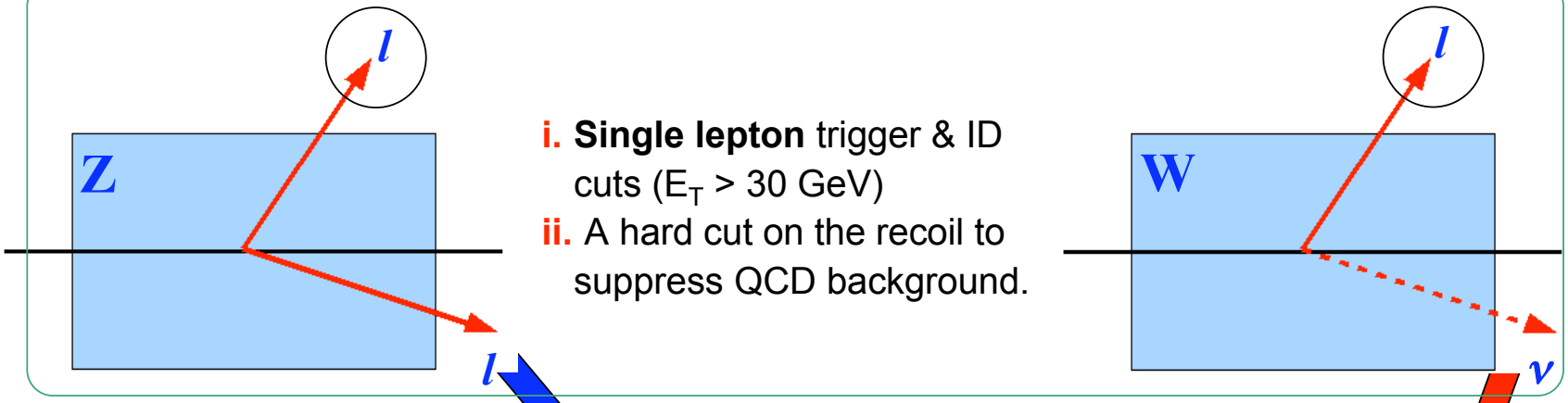
$$g_\mu / g_e = 0.997 \pm 0.010$$
$$g_\tau / g_e = 1.036 \pm 0.015$$
$$g_\tau / g_\mu = 1.039 \pm 0.014$$

**LEP-2**



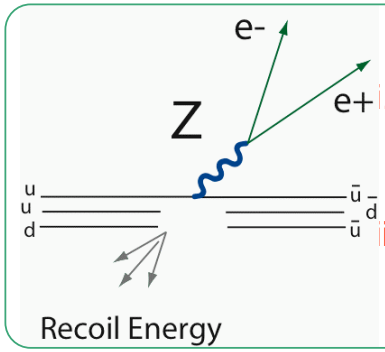
# R(W/Z) : New Method

1. Design an analysis optimized for the ratio of cross-sections.
2. Start with a selection entirely symmetric between W's & Z's :

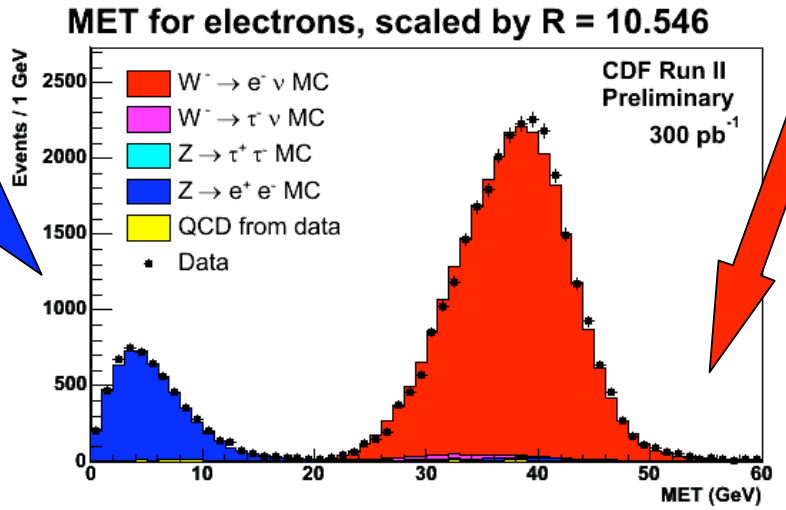



i. **Single lepton** trigger & ID cuts ($E_T$ > 30 GeV)
ii. A hard cut on the recoil to suppress QCD background.

3. Fit for W & Z fractions in a discriminating variable, $\not\!\!E_T$ :




i. Exclude 2nd EM object from recoil.
i. Include all towers in $\not\!\!E_T$ calculation.



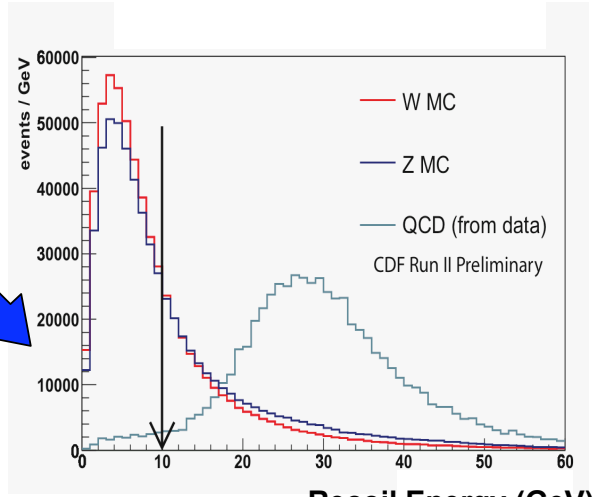
# R(W/Z) : New Method

| CDF PRELIMINARY | ΔR/R (%) | |
|---|---|---|
| | electron (72 pb$^{-1}$) | electron (300 pb$^{-1}$) PRELIMINARY |
| Statistical | 1.7 | 0.94 |
| PDF | 0.65 | 0.31 |
| Material | 0.28 | - |
| Recoil | 0.28 | 0.40 |
| Efficiency | 1.10 | - |
| Background | 0.37 | 2.5 |
| Missing-$E_T$ | - | 0.5 |
| Total Systematic | 1.50 | 2.60 |
| Stat. + Syst. | 2.20 | 2.76 |

- Reduced by x2
- Eliminated.
- Increased: needs better understanding

Preliminary systematic study & comparison with earlier analysis.

Recoil distribution for signal & QCD background




$$R = 10.55 \pm 0.09\ (\text{stat}) \pm 0.27\ (\text{syst})$$

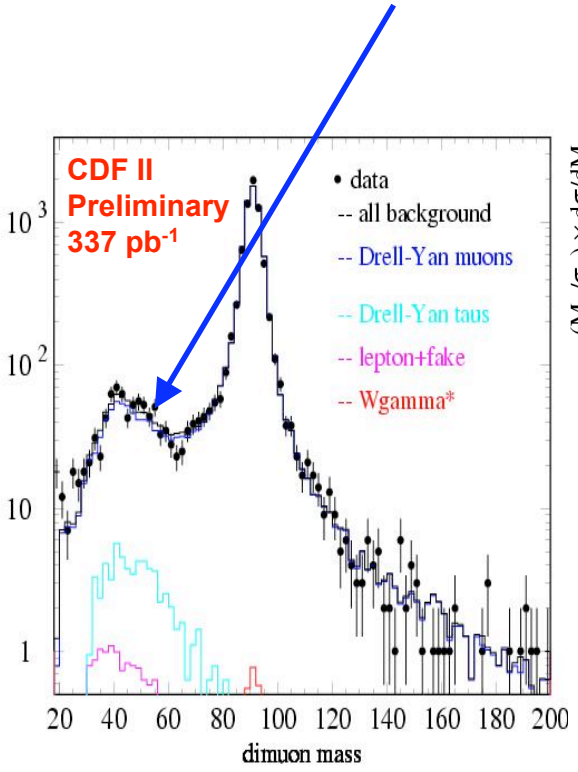
CDF e PRELIMINARY, 300 pb$^{-1}$

# Drell Yan

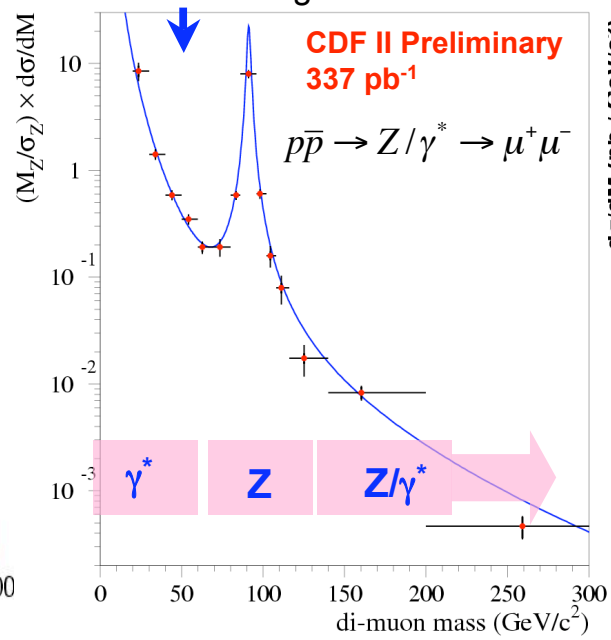
$$p\bar{p} \rightarrow Z/\gamma^* \rightarrow l^+l^- \quad (+X)$$

- A standard measurement at hadron colliders :
  - control sample for searches (Z', SUSY dilepton channels)
  - PDF constraints.

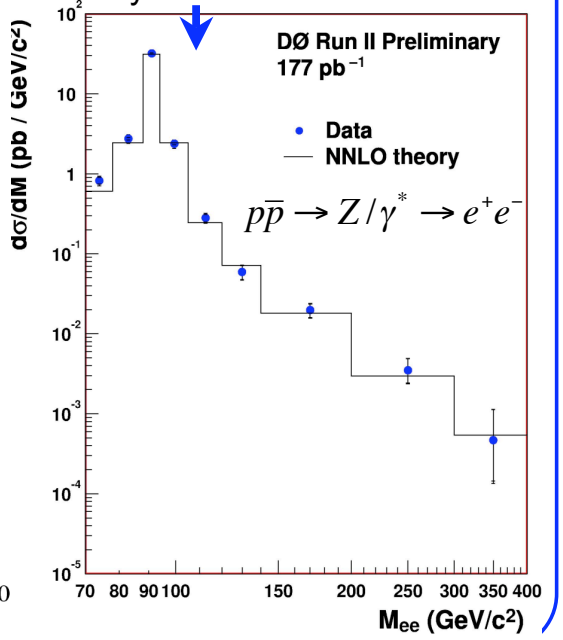
Triggers/cuts distort low mass region




matrix unfolding

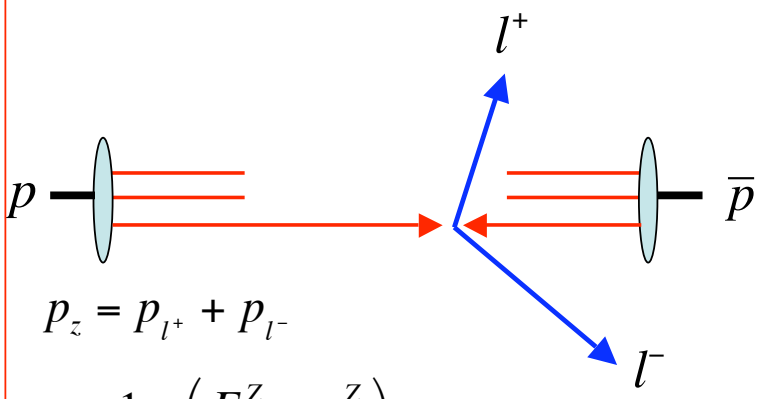



bin-by-bin correction



# PDFs : Drell-Yan dσ/dy

Rapidity differential cross section :



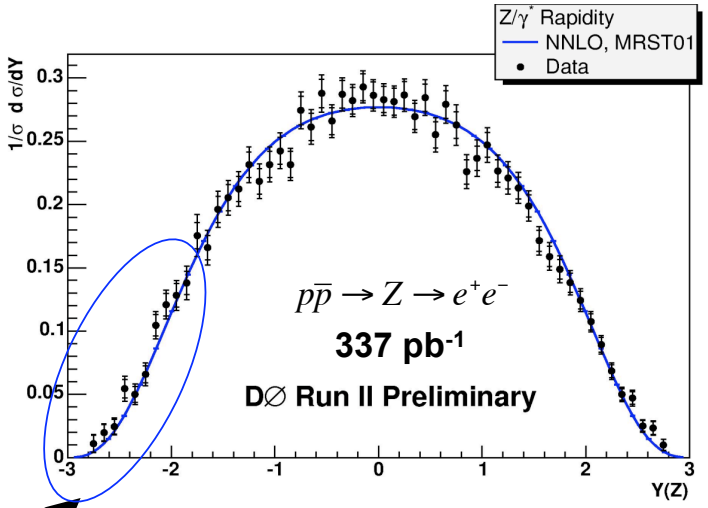

$$p_z = p_{l^+} + p_{l^-}$$

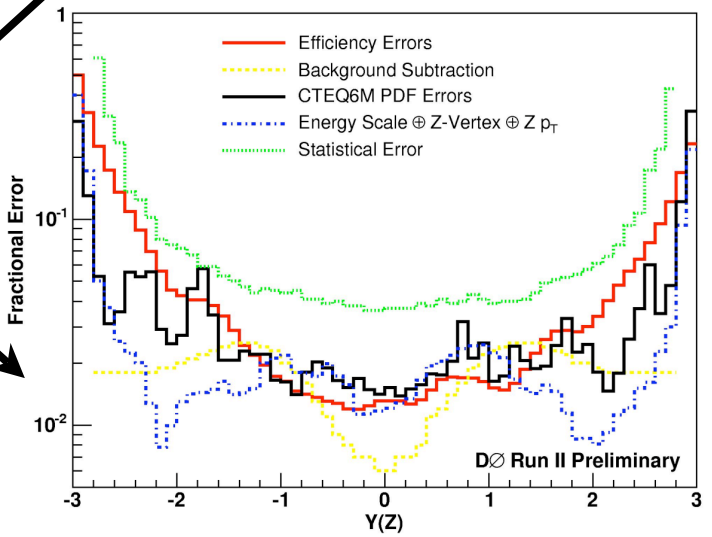
$$y = \frac{1}{2}\ln\left(\frac{E^Z + p_z^Z}{E^Z - p_z^Z}\right)$$

- At leading order :

$$x_p, x_{\bar{p}} = \left(\frac{M}{\sqrt{s}}\right) e^{\pm y}$$

- High-y → high-x
- Currently statistically limited.



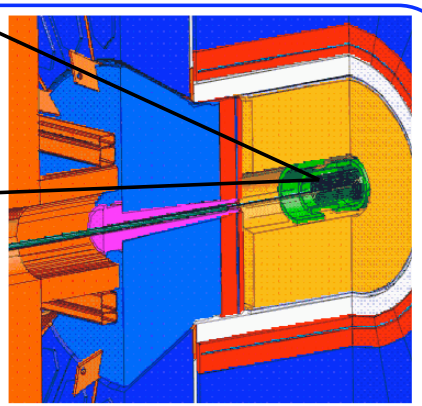



# PDFs : $\sigma_W$ (forward region)

- A new & technically challenging analysis :
  - Silicon tracking for electron ID
  - Backgrounds

$$\sigma_W \cdot BR(W \rightarrow e\nu) =$$
$$2.796 \pm 0.013\ (\text{stat})\ ^{+0.095}_{-0.090}\ (\text{sys}) \pm 0.168\ (\text{lum})\ \text{nb}$$

$$1.2 \le \eta_e \le 2.8$$
$$E_T^e > 20\ \text{GeV}$$
$$\not{E}_T > 25\ \text{GeV}$$

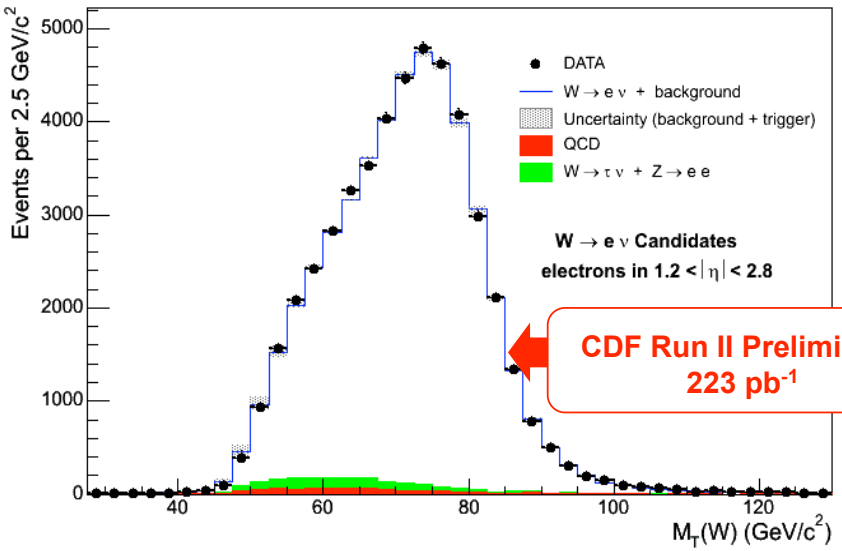


- Compare with central analysis :

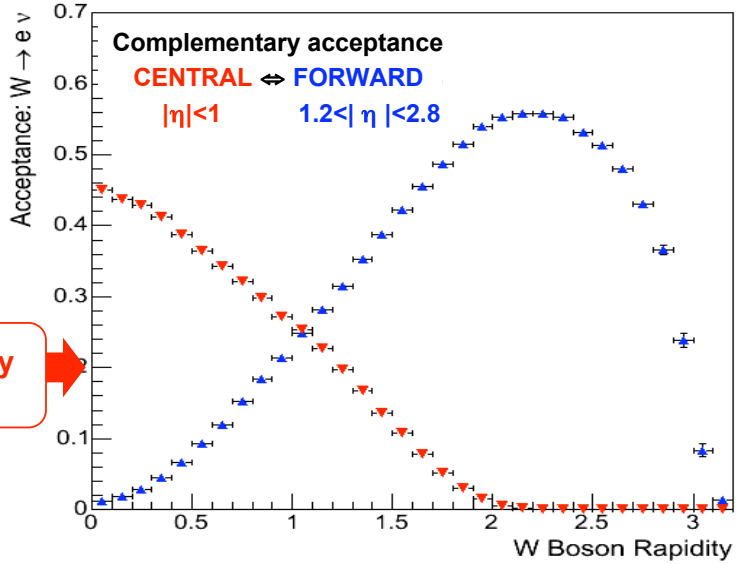
$$R_{\text{exp}}^{central\,/\,forward} = 0.925 \pm 0.033$$

$$R_{CTEQ\ 6.1}^{central\,/\,forward} = 0.924 \pm 0.037$$
$$R_{MRST\ 01E}^{central\,/\,forward} = 0.941 \pm 0.012$$

**PDF constraint**




**CDF Run II Preliminary**
**223 pb$^{-1}$**



# Conclusions

- The Tevatron experiments have completed a first round of W & Z measurements: :
  - Inclusive cross-sections
  - Differential cross-sections
  - Asymmetries (see Susan Blessing's talk)

- Results here based on 400 $pb^{-1}$ of data
- Expect final Run II results to have 10-20 times this

- A next generation of measurements are being designed for enhanced sensitivity to the underlying physics parameters (couplings, PDFs etc.) which requires reducing systematics through the development of new analysis techniques and extending the kinematic coverage.

- These results are helping to :
  - Understand the environment for a precision W mass measurement
  - Optimise understanding of detector and backgrounds for new physics searches